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UCRL- 85993
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CONF- 811040- -44

# Design and Fabrication of Liquid Nitrogen Thermal Shields for the MFTF Yin-Yang Magnets


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This Paper was Prepared for Submittal to
9th Symposium on Engineering Problems
of Fusion Research
IEEE, Chicago, IL October 26-29, 1981


October 12, 1981

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DESIGN AND FABRICATION OF LIQUID NITROGEN THERMAL SHIELDS FOR THE MFTF YIN-YANG MAGNETS*

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## Summary

This paper documents the design and fabrication of thin liquid nitrogen-cooled panels installed on the 340-tonne MFTF yin-yang superconducting magnet system. These panels were installed to shield the 310-m$^2$, 4.5 K magnet surfaces and the liquid helium supply piping for the magnet from thermal radiation coming from the vacuum vessel walls and the water-cooled plasma shields. Heat flow into the magnet system must be minimized to avoid high heat loads which could prevent the magnet from becoming superconducting or exceed the capacity of the helium liquifier system. The liquid nitrogen shields will also be used to carry warm gaseous nitrogen for magnet warmup and surface regeneration. The thermal shield system is installed in a thin region over the entire surface of the magnet. The 344 panels are made of [illegible] stainless steel with the [illegible] flow channels formed by inflation with a high pressure gas. [illegible] the manufacturer to thermal shock the panels with $LN_2$ and then vacuum leak check them with He. The thin-walled panel supports are made from an epoxy base, fiberglass [illegible] which is reliable at cryogenic vacuum conditions. [illegible] and reliable welding of the manifold system was assured using [illegible] of automated tube welder, on the more than 3000 feet of tubing and 3000 butt-weld fittings. To assure sufficient flow for single-phase $LN_2$ flow conditions, we performed a hydraulic network flow analysis. This allowed for some optimization of shield inlet-flow conditions and manifold design. To verify operating fluid pressure and temperature, special pressure transducers and platinum resistance thermometers capable of operation at cryogenic conditions in a vacuum, high magnetic field, and long-term neutron bombardment were installed. Final assembly is complete. The final installation on the magnet was difficult due to the orientation of the magnet assembly and the restricted access to some installation surfaces.

## Introduction

The Mirror Fusion Test Facility (MFTF) is a Lawrence Livermore National Laboratory (LLNL) fusion research project that includes a 340-tonne yin-yang superconducting magnet system contained in a 12-m-diameter by 18-m-diameter long vacuum vessel. Limiting heat flow into the magnet system is crucial to successful operation of the MFTF magnet. High heating rates can prevent the magnet from becoming superconducting or exceed the capacity of the helium (He) liquifier system. The magnet pair and its associate He piping are to be shielded from thermal radiation by covering all its external surfaces with liquid nitrogen ($LN_2$)-cooled panels mounted on the magnet surfaces (Fig. 1). Heat conduction into the magnets is restricted by $LN_2$ cooling the hanger and stabilizer struts and by using low thermal conductivity panel supports. In this paper we describe the design and operation of the MFTF magnet $LN_2$ shield system (frequently referred to as the magnet liners).

* Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

## System Requirements

[illegible] system requirements for these liners [illegible]:

1. Provide a low thermal emissivity, $LN_2$-cooled shield for magnet system surfaces for operation in a $10^{-7}$ torr vacuum.

2. [illegible]mit combined leak rates of the magnet systems [illegible] thermal shields to $10^{-7}$ torr-liter He/sec.

3. Use these liners to provide a heat source for [illegible] the magnet system surfaces.

4. Re[illegible] the heat load to the magnet cases.

5. Pr[illegible] mechanical support for added water-cooled [illegible]ls, gas boxes and plasma [illegible]mentation.

6. [illegible] 1000 thermal cycles between room temperature and cryogenic conditions.

## Panel Design and Fabrication

The magnet liners are thin panels which are convectively cooled inside by $LN_2$. The surfaces covered by the liners include the magnet case, magnet helium supply and return ducts, and magnet current lead ducts (Fig. 1). The liners and associated manifolding are installed over the magnet surface in a thin zone ranging from 1" to 8" thick (Fig. 2). The radiation heat load on the liner system from the vessel wall and water-cooled liners at 300 K is 35 kW. The heat load is based on a 0.3 maximum thermal emissivity for the convectively-cooled panels and 1.0 for the vessel wall. The liner flow bulk temperature is enough below the saturation temperature to avoid bulk boiling which could cause a panel to be isolated from the $LN_2$ supply due to vapor lock. The maximum allowable temperature rise for the $LN_2$ operating at 90 psia inside the vessel portion of the liner system is 10 K. The liner system is designed so that it might be drainable by gravity for quick panel cooldown and warmup. The structural capability of the liner system and its supports include a design requirement to resist an additional 1 g seismic acceleration force over the normal static weights. The panel material is stainless steel to assure low magnetic susceptibility after multiple thermal excursions between room temperature (300 K) and $LN_2$ temperature (80 K). The panels are sized for convenient installation and removal. The supports are made of low thermal conductance material to minimize the heat transferred to the magnet from the liners. These supports are designed to retain retain good strength under the high energy neutron fluxes and cryogenic temperatures expected.

The panels are made from two sheets of 316L stainless, seam-welded along the edges and spot-welded over the interior. After the welds are completed, the panel is pneumatically inflated to provide the flow passages for the $LN_2$ and electropolished (Fig. 3). This type of panel has been used successfully at LLNL for a variety of magnetic fusion experiments (e.g. Baseball, TMX, 2XII-B). Although each region on a magnet has seven additional similarly shaped regions on other portions of the magnet pair, penetrations of the liner system by ducting and hanger supports tended to increase the variety of panels. One advantage of designing with these pillowed panels was the ease of allowing for these penetrations. Another was the low pressure loss for flow within the panels. At the manufacturing plant, the panels were thermally cycled three times between room temperature and $LN_2$ temperature, pressure proof tested to 200% of operating pressure and vacuum leak checked with helium to show a leak rate less than $1 \times 10^{-9}$ std. cc He/sec.

Because of space requirements, certain areas could not be convectively cooled, such as those on the beveled area of the magnet (Fig. 4). These are constructed from nickle-plated copper sheet attached along its edges to convectively-cooled panels. All panels are supported on the magnet system surface using G-10 CR grade thin wall box beam structures. The design of these supports is discussed in Paper 07-022 of this Conference (Fig. 4). To allow for tolerances in magnet and panel manufacture, a 1"-wide gap was left around each panel. To shield the magnet in these areas between panels from 300 K thermal radiation, 1"-wide polished aluminum 1100-H14 anti-shine-through shield strips were pop-riveted to the edges of each convectively-cooled panel (Fig. 5).

The added heat load to the magnet for the region not covered by pillowed panels is approximately 30 watts. In all there are 344 panels covering 1200 ft$^2$ and weighing 16,000 pounds. The total heat conducted to the magnet system through the supports is 62 Watts and the total radiation heat load transferred to the magnet is about 370 Watts.

## Piping Design and Fabrication

The piping for the magnet liner system is divided into four main groups: a) piping external to the vessel, b) vessel port piping feed-through and main internal supply lines, c) manifolding for panels on the magnet surface, and d) manifolding for the panels on the auxiliary ducting. A small group of additional lines were included to provide $LN_2$ to the thermal isolation cans of the magnet hangers. Because these lines are required to carry gaseous nitrogen during magnet surface regeneration and liner system cooldown, the pipes were sized for reasonable pressure loss for gaseous flow. Right-of-way for the piping off the magnet was controlled by the vessel cryopanel piping and vessel diagnostic port locations. On the magnet surface the piping follows the thin right-of-way set apart for the liner system (Fig. 2). The other design requirements for the liner piping are the same as for the liner panels.

The large number of panels and the small volume available for piping on the magnet surface imposed a complex piping manifold on the design (Fig. 6). The piping is assembled so close to some panels that manual tube welding was all but impossible. A pair of automated tube TIG welding units were used in the manifold assembly to accomplish these welds and to provide for a more rapid assembly and a higher quality welded structure. With the choice of automated tube welding for the primary piping assembly tool, most piping junctions were designed using butt weld tube fittings commonly used with this assembly technique. Simple, inexpensive, low thermal conductance supports were designed to support the piping off the liner panels or at the vessel wall (Fig. 5).

An even flow distribution between panels was most desirable to assure that none of the panels were starved of sufficient flow to remove the expected thermal radiation heat load. A hydraulic network analysis was used to modify the initial manifold design to assure as even a $LN_2$ flow distribution as possible. Spatial and hookup restrictions limited the amount of network modifications possible. The final total $LN_2$ flow defined by this analysis was 70 gpm, up from the 35 gpm minimum required by the thermal load.

To check the actual flow conditions, platinum-resistance thermometers and pressure transducers were installed at eight sites throughout the liner piping system. Since the expected temperature rises and pressure losses are relatively small, high accuracy sensors were used. These sensors were designed to work in an extreme operating environment, i.e., cryogenic temperatures, high neutron fluxes, high magnetic field, and hard vacuum conditions.

## Assembly and Installation

The yin-yang magnet pair was joined and moved to the front of the vacuum chamber on a large transporter. The magnet surface portion of the liner system was installed on the magnet as it sat on the transporter outside the vacuum vessel. Because the magnets are oriented at a 45° angle, it was very difficult for the technicians to assemble and install the liners in some areas. Since common mechanical lifting devices don't provide ready access to many of these areas, panels and piping modules were sized for easy two-man moving and installation. For cleanliness requirements the liner system was essentially assembled in a top-down order. Figure 7 shows the completion of the magnet surface portion of the panel and manifold installation. It was pressure proof tested and vacuum-checked for leaks with He before the magnet assembly was inserted in the vessel. Once the magnet was hung in the vessel and the current leads and He supply lines were installed, the remaining portion of liner system was installed (Fig. 8).

## Acceptance Testing

Throughout the fabrication and installation of the magnet liners, acceptance tests were performed to qualify the system and components. The liner panel acceptance tests included pressure proof tests, thermal cycling and He leak checks at the manufacturer and LLNL. Modules of the installed liner system were also subjected to these same pressure proof tests and He leak checks. The composite panel supports were qualified by material and by design in room temperature tensile and shear tests. The functional tests for qualifyilng the whole liner system are expected to be completed on the system in FY82. They involve prechilling the panels and piping with cold gaseous nitrogen ($GN_2$) before filling the system with $LN_2$. Temperature rise and pressure loss measurements will be made to compare with expected maximum values. After the magnet has cooled to superconducting temperatures and its performance is determined, the liner system will be cycled to the surface regeneration mode using room temperature $GN_2$. A check of the emergency shutdown mode will involve gravity draining the $LN_2$ from the liner system and allowing the magnet to warm slowly to room temperature.

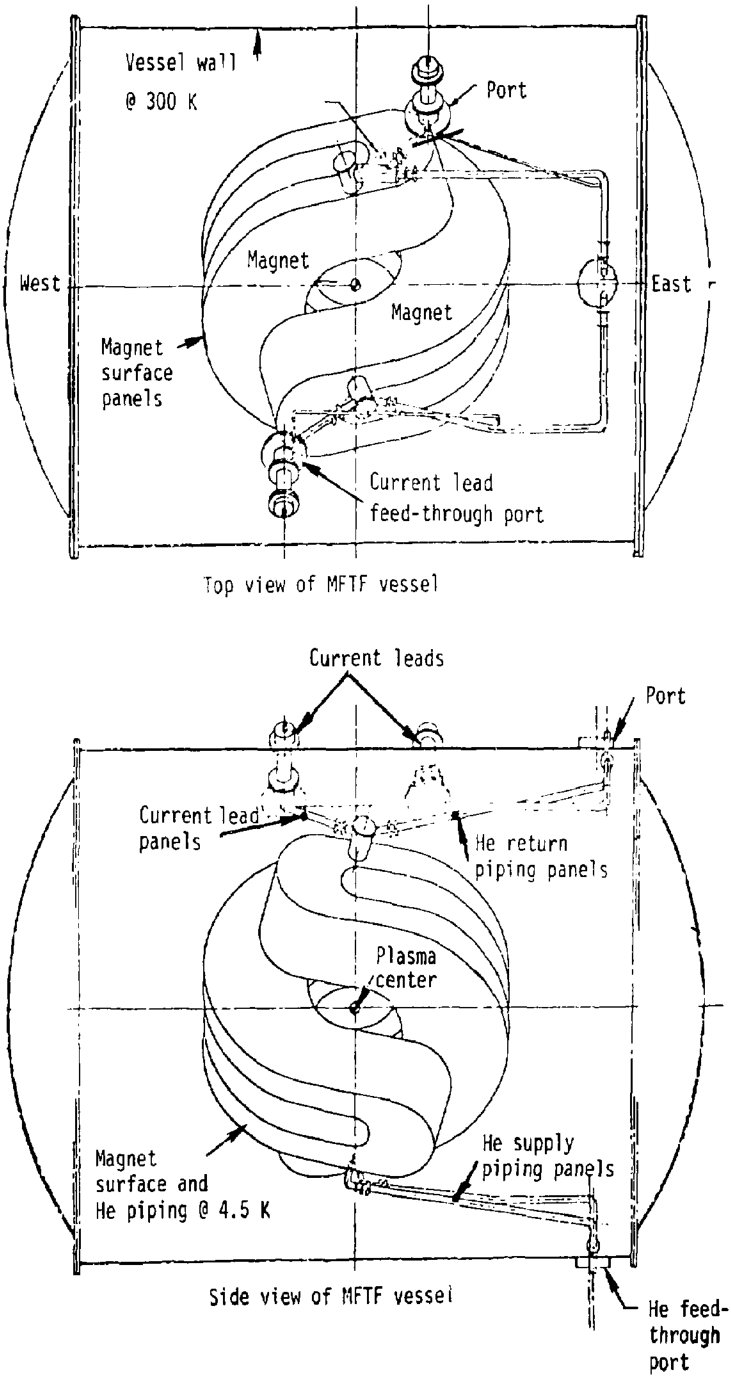



Fig. 1 The magnet pair and its He piping are to be shielded from thermal radiation by covering its external surfaces with $LN_2$-cooled liners.

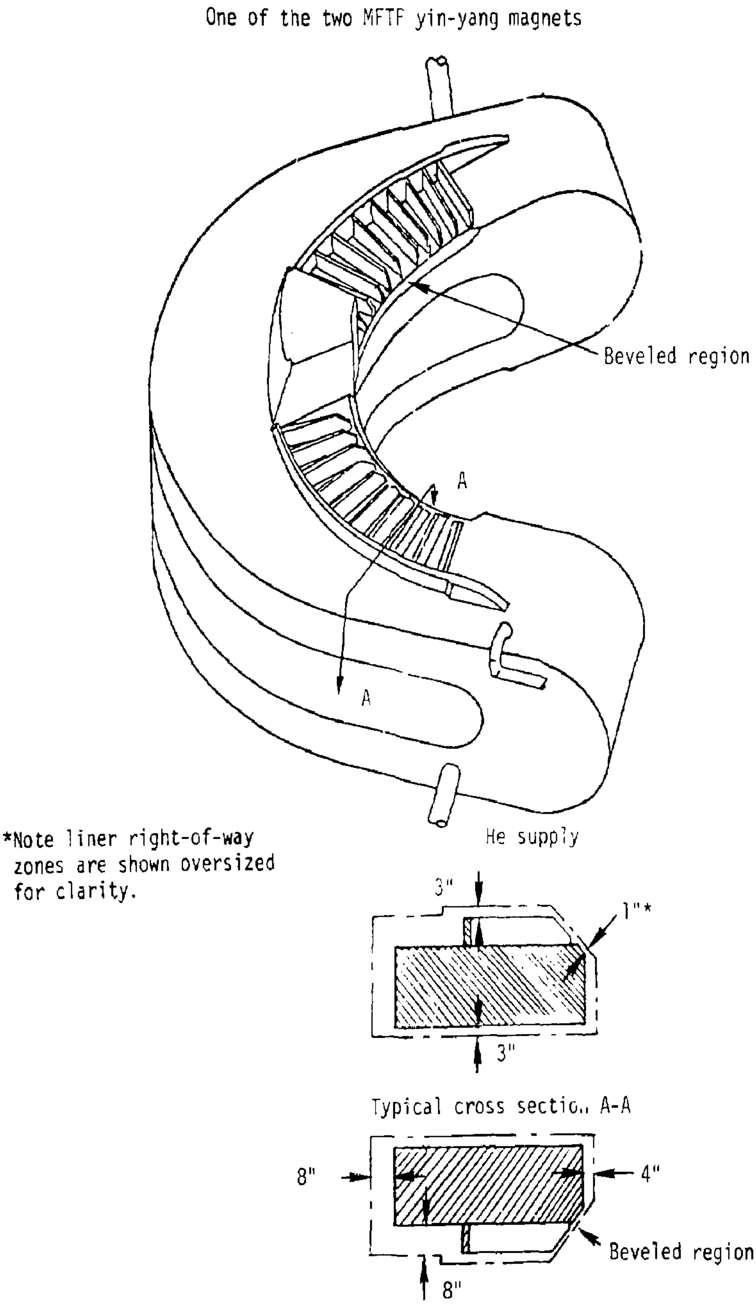
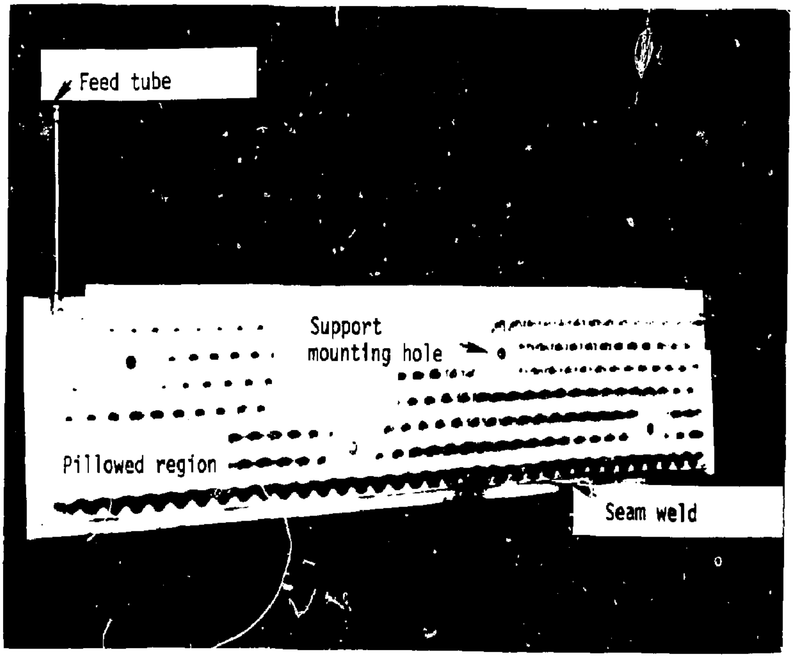



**Fig. 2** **The liners and associated manifolding are installed in a thin zone over the magnet surface in a thin zone ranging in thickness from 1" to 8".**



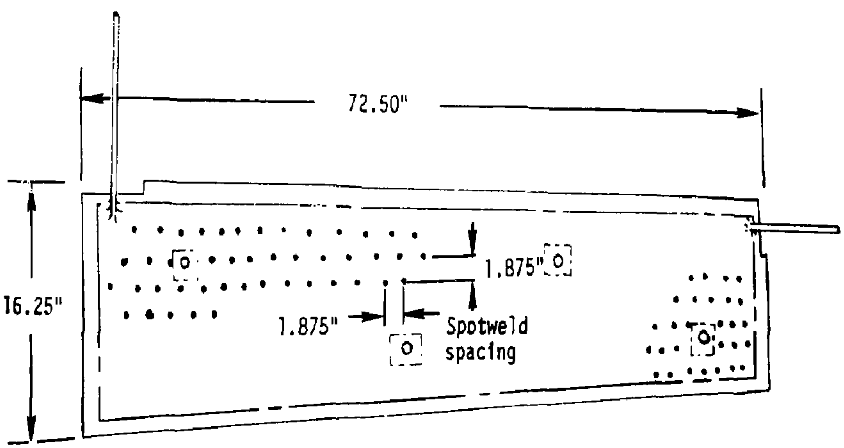




Fig. 3 The liners are made from two sheets of 316 L stainless steel welded together and inflated pneumatically to get the $LN_2$ flow passages.

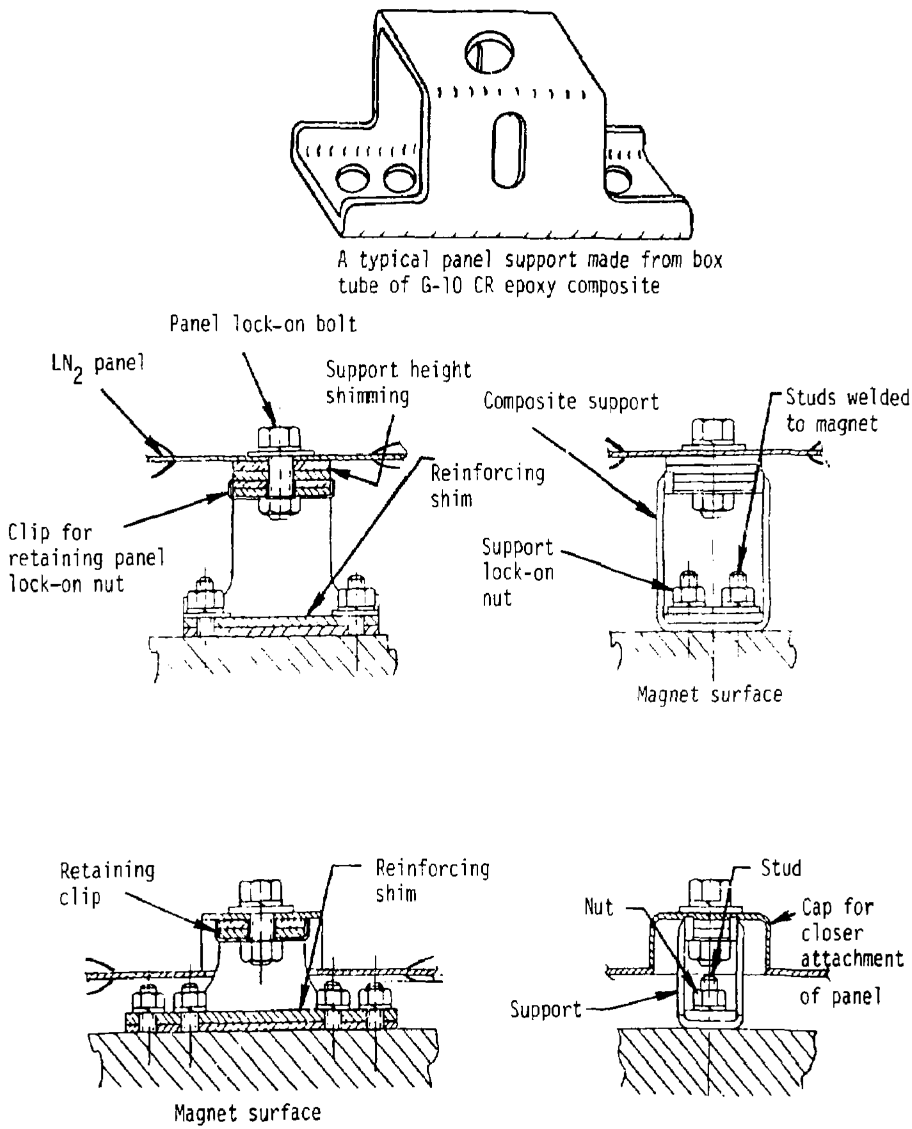
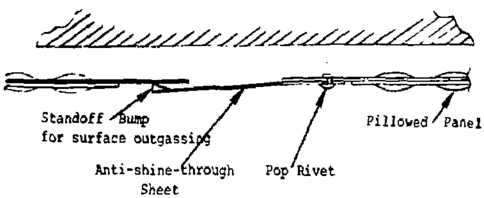
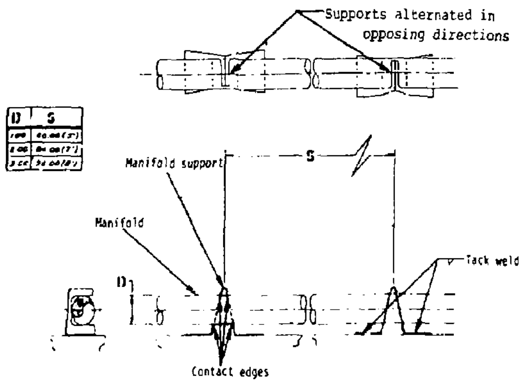


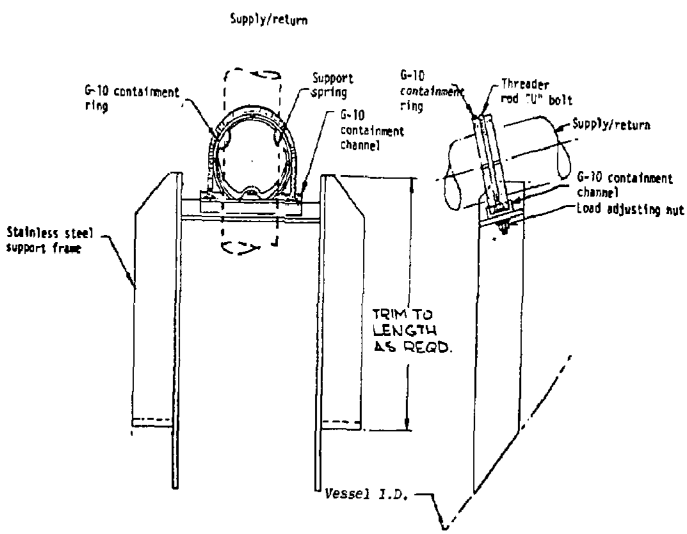

Fig. 4 The panels are supported on the He-cooled surfaces by thin wall box tube structures of a low thermal conductance epoxy composite.




a. Anti-shine-through design




b. Magnet surface manifold support design




c. $LN_2$ supply/return support design

Fig. 5 The individual details for anti-shine-through protection and piping support required some of the most creative design effort.

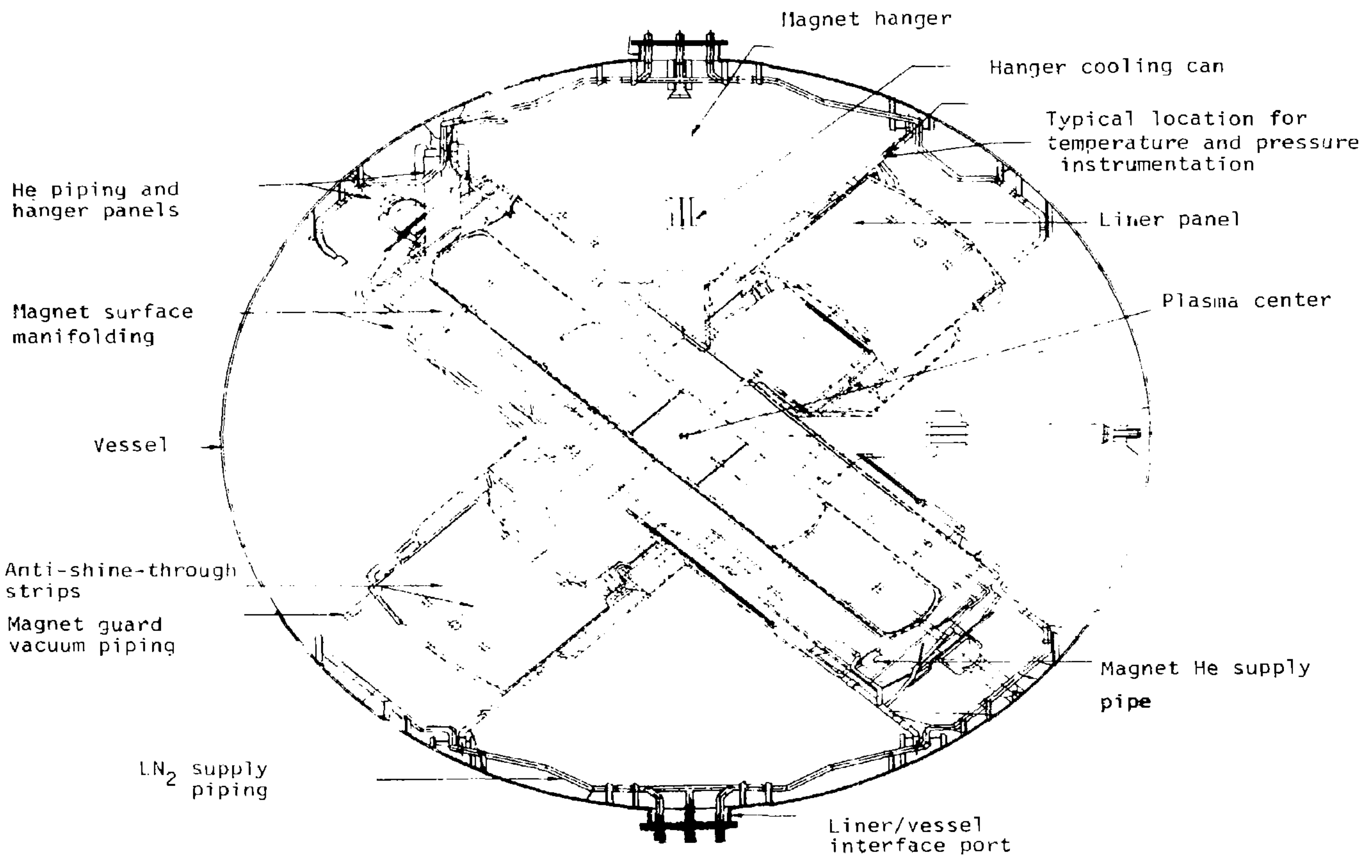



Fig. 6 Final liner piping was very complex to satisfy all the requirements.

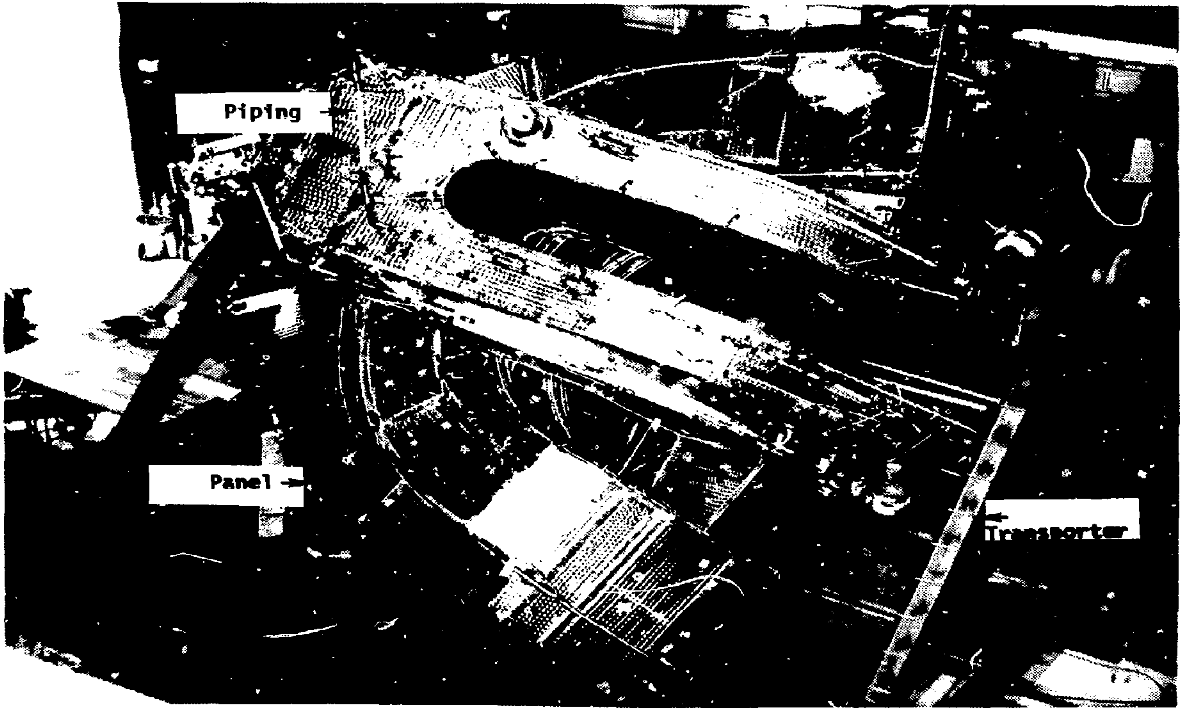



Fig. 7 The completed magnet/liner system sitting on its transporter in front of the vacuum vessel.

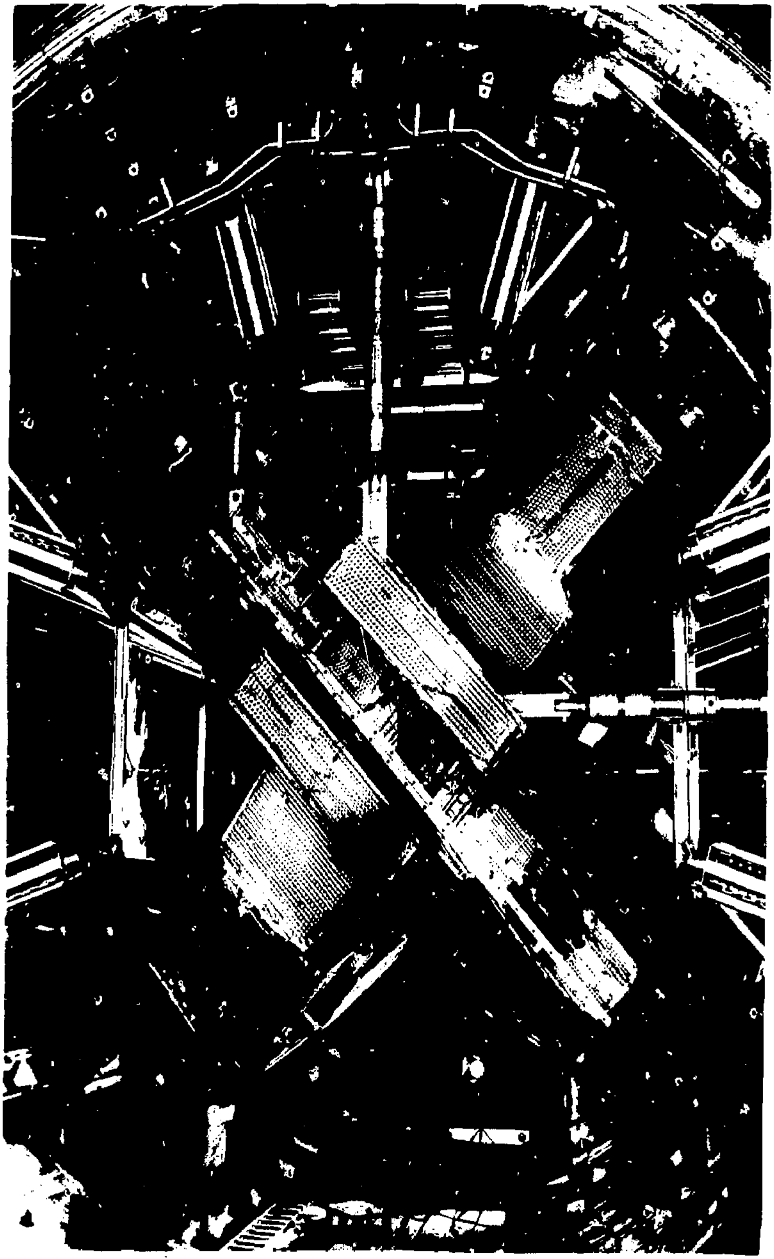


Figure 8. The final assembly of the liner panels and piping on the helium supply piping and current leads took place with the magnet hanging in the vessel.